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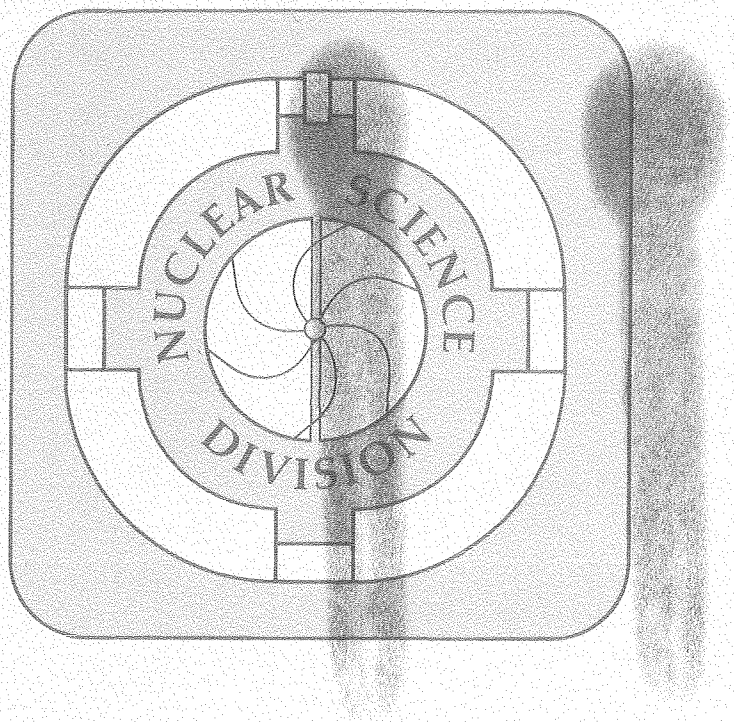
April 1981



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Λ Production Near Threshold in Central Nucleus-Nucleus Collisions

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ABSTRACT

Λs produced in central collisions of ^{40}Ar + KCl at 1.8 GeV/u incident energy were detected in a streamer chamber by their charged-particle decay. For central collisions with impact parameters $b < 2.4$ fm the Λ production cross section is 7.6 ± 2.2 mb. A calculation in which Λ production occurs in the early stage of the collision qualitatively reproduces the results but underestimates the transverse momenta. An average Λ polarization of -0.10 ± 0.05 is observed.

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In the study of high energy nucleus-nucleus collisions it is difficult to extract information about the initial stage of the reaction where high baryon densities may occur. Studies of nucleon and cluster emission[1] are consistent with a development towards chemical equilibrium in the final stages of the reaction preempting information about the primary stages. In this Letter we report the results of Λ production in central nucleus-nucleus collisions, just above the $NN \rightarrow \Lambda KN$ threshold. Λ production near threshold is expected to occur either in the first generations of binary nucleon-nucleon collisions or from a localized collective high temperature, high density system and in any case to reflect the first stages of the interaction. Although rescattering of particles in the nuclear medium is expected to be important, the absorption of Λs is minimal. Therefore, the study of Λ production would provide a new way to examine the interpenetration phase of nucleus-nucleus collisions.

Strange baryon production near threshold in nucleus-nucleus collisions is interesting since it provides an opportunity to test the effect of an extended nuclear field on the production mechanism[2]. In the elementary $NN \rightarrow \Lambda KN$ process, a strange-antistrange quark pair must be produced from the sea[3].The existence of strange-antistrange quark admixtures[4,5] in the nucleus may enhance the strange baryon production near threshold.

Λ production was studied in central ^{40}Ar + KCl collisions at 1.8 GeV/u incident energy using the Streamer Chamber facility at the Bevalac. The streamer chamber, with its 4π solid angle capability, was operated in both inelastic and central trigger modes as previously reported[6]. The central trigger selects events with small total charge in projectile fragments. This trigger, which corresponds to 10% of the reaction cross section (σ_R = 1.8 b), is associated with impact parameters b < 2.4 fm in

a geometric model. The open channels for production of strange particles in this energy regime are $NN \rightarrow \Lambda KN$ (1.58 GeV), $\rightarrow \Sigma KN$ (1.79 GeV), and $\rightarrow \Lambda KN\pi$ (1.96 GeV). Neutral strange particles were detected by their charged-particle decay in the active volume of the chamber. In order to derive Λ production cross sections and momentum spectra, detection and scanning efficiencies were determined. The detection efficiency is intrinsically a function of the branching ratio for charged-particle decay, the momentum of the decaying neutral particle, its lifetime, and the fiducial volume of the detection apparatus. To eliminate efficiency problems due to the high track density near the primary reaction vertex, only neutrals decaying farther than 10 cm from the target center were accepted. With appropriate efficiency corrections the average weight per Λ event for the observed sample was $\sim$3. The neutral strange particles identified by a kinematical fit of the decays $\Lambda \rightarrow p\pi^-$ and $K^\circ \rightarrow \pi^+\pi^-$ are displayed in the $m(p\pi^-)$ vs $m(\pi^+\pi^-)$ invariant mass plane in Fig. 1. There are two distinct bands corresponding to the Λ and K° masses. The low number of K° decays observed is due to the mismatch between the effective fiducial volume of the chamber and the lifetimes of the K°_S ($c\tau$ = 2.68 cm) and K°_L ($c\tau$ = 1554 cm). It should be noted that any Λ originating from Σ° production (100% branching ratio for $\Sigma^\circ \rightarrow \Lambda\gamma$ decay) would be included in these data[7].

The identified Λs are displayed in Fig. 2a as a function of $p_\perp$ and $p_\parallel$ in the nucleus-nucleus c.m. system. The solid curve in Fig. 2a represents the kinematic limit for Λ momenta produced in the elementary $NN \rightarrow \Lambda KN$ reaction at 1.8 GeV. Most of the Λs are observed beyond the limit indicating the necessity to include Fermi motion and/or collective multi-particle interactions. To investigate further the origin of the observed high Λ momenta, a Monte Carlo phase space calculation incorporating Fermi

motion of nucleons in both nuclei was carried out. A gaussian Fermi momentum density distribution with a σ = 90 MeV/c was employed[8] and the Λs were produced in an elementary $NN \rightarrow \Lambda KN$ process with a uniform phase space distribution[9]. The results after folding in the detection efficiencies are shown in Fig. 2b. The distribution, which peaks at p = 0, is broadened in phase space but still does not adequately describe the observed spectrum.

Inclusion of Λ rescattering in the nuclear medium was next considered by adopting the simple approach of Ref. 10. In this model the geometry is assumed to be two partially overlapping spheres of normal nuclear matter density subject to the usual Lorentz contractions. The mean number of ΛN collisions was found to be n_o = 1.86 using the ΛN elastic cross section[11] $\sigma_{\Lambda N}$ = 20 mb. In each collision the Λ scatters from a baryon whose momentum is obtained from a chosen momentum density distribution. The angular distribution was taken to be isotropic in the Λ-baryon rest frame. The baryon momentum distribution was assumed to be either of two extremes: a thermal "fireball" distribution[12] in the nucleus-nucleus c.m. with T_o = 120 MeV (RsI) or a superposition of the initial distributions of baryons in the two incident nuclei represented by two moving (Lorentz contracted) gaussian Fermi momentum distributions (RsII). Rescattering from the thermal "fireball" distribution (RsI) has little effect on the Λ spectrum. However, rescattering from a superposition of the colliding initial distributions (RsII) shown in Fig. 2c depletes events from the central peak and creates peaks near $p_{\parallel} = \pm 0.8$ GeV/c. The backward peak at $p_{\parallel}$ = -0.8 GeV/c is suppressed by the detection efficiency which is included in the calculation. In addition, the $p_{\perp}$ is boosted in qualitative agreement with the observations.

A quantitative comparison of the data with results of the Monte Carlo calculations can be found in Table I where the mean and rms values of $p_\perp$ and $\left|p_\parallel^{cm}\right|$ for the invariant $\frac{E}{2\pi p_\perp}\frac{d^2\sigma}{dp_\perp dp_\parallel}$ distributions are presented. The data exhibit a much higher $\langle p_\perp \rangle$ than predicted by any of the calculations. The RsII calculation which most closely approximates the observed $\langle p_\perp \rangle$ predicts too large a value for $\langle \left|p_\parallel\right| \rangle$. Other possibilities which could influence these results have been explored. One mechanism of importance to Λ production[13] is intermediate Δ formation. To test whether the experimental results are sensitive to the process $NN \rightarrow \Delta N$ followed by $\Delta N \rightarrow \Lambda KN$, further calculations including Fermi motion and this 2-step process were carried out. The resultant spectrum of Λs was found to be similar to that produced in NN interactions as shown in Row 4 of Table 1. A more elaborate cascade calculation is needed; furthermore, additional effects such as high density in the initial stages of the collision either in short-range correlations or hydrodynamic flow may be necessary to describe the observed Λs.

The topology for Λ producing events does not differ from the rest of the central trigger events. The mean π^- and total charged-particle multiplicities are found to be the same for events with or without Λs. In both cases $\langle n_{\pi^-} \rangle \simeq 6$ and $\langle n_{tot} \rangle \simeq 42$. The mean Λ multiplicity is found to be $\langle n_\Lambda \rangle = 0.04$ for the central trigger. Using the measured cross section for central trigger events[6], $\sigma = 180$ mb, the Λ cross section in central collisions of ^{40}Ar + KCl at 1.8 GeV/u is found to be $\sigma_\Lambda = 7.6 \pm 2.2$ mb. A multiple collision model employing a linear cascade[13,14] with impact parameter selection $b < 2.4$ fm predicts a $\Lambda + \Sigma$ cross section of $\sigma \sim 10$ mb. There is a large uncertainty in the prediction due to the absence of $pp \rightarrow (\Lambda, \Sigma) + X$ production data at these low energies.

Since Λ decay is self-analyzing for polarization in the decay process $\Lambda \rightarrow p\pi^-$, the distribution of decay protons in the Λ decay frame relative to the Λ spin direction[15] is $dW/d\Omega = (1 + \alpha P\cos\theta)/4\pi$ where P is the Λ polarization, $\alpha = -0.642$[16], and θ is the angle between the decay proton and the unit vector normal to the plane. Using the relation[17] $\alpha P = \langle\cos\theta\rangle/\langle\cos^2\theta\rangle$, the polarization extracted from the present experiment was found to be $P = -0.10 \pm 0.05$. A Λ polarization has been observed at higher energies in pp reactions[18]. This polarization has been ascribed to the spin features of the SU(6) quark wavefunctions[18,19] whereby the spin of the Λ is determined by that of the produced strange quark. The $|P|$ is observed to increase with $p_\perp$ and has the same values for incident energies 24-400 GeV. The small sample of Λs from the present experiment does not allow for such an analysis.

In summary, Λs have been studied in collisions of ^{40}Ar + KCl at 1.8 GeV/u incident energy just above the NN threshold. The average Λ polarization was found to be $P = -0.10 \pm 0.05$. The Λ production cross section is $\sigma_\Lambda = 7.6 \pm 2.2$ mb for the central trigger mode. In a Monte Carlo calculation it is necessary to include Fermi motion and rescattering from the initial momentum density distributions to reproduce qualitatively the Λ momentum phase space. This is consistent with the hypothesis that Λs are produced in the initial stage of the reaction rather than in the later thermal phase. The high $\langle p_\perp \rangle$ observed in the data cannot be reproduced in the framework of these calculations which are based on a direct $NN \rightarrow \Lambda KN$ production mechanism in the first binary encounter. Recent Monte Carlo-cascade calculations[20] exhibit a central density pileup of four times normal nuclear matter density in the first few generations of interactions. In such calculations there is local equilibrium in the high density region

but global nonequilibrium. Such high density regions may provide a way for producing Λs with higher $p_\perp$ than in a direct process.

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TABLE

1. Mean and rms values of $p_\perp$ and $\left|p_\parallel^{cm}\right|$ for the invariant $\frac{E}{2\pi p_\perp}\frac{d^2\sigma}{dp_\perp dp_\parallel}$ distributions of the data and calculations described in the text. $\langle p_\perp^2\rangle$ can be extracted from the table using the relation $\sigma(p_\perp) = [\langle p_\perp^2\rangle - \langle p_\perp\rangle^2]^{1/2}$.

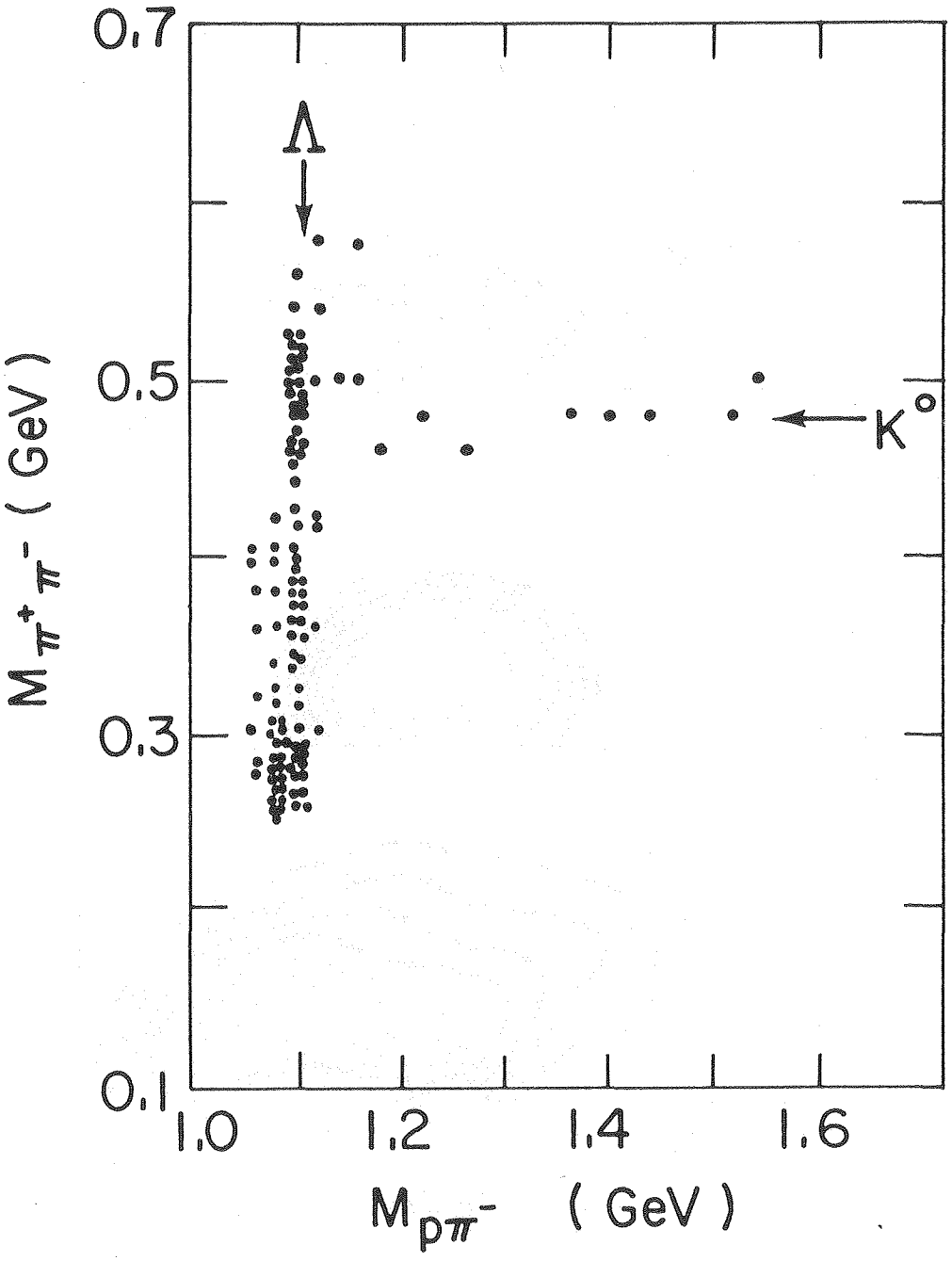
FIGURE CAPTIONS:

1. Results of kinematic fits to the observed neutral strange particle decays, $\Lambda \rightarrow p\pi^-$ and $K^\circ \rightarrow \pi^+\pi^-$, plotted in the invariant mass plane $m(p\pi^-)$ vs $m(\pi^+\pi^-)$.

2. $^{40}Ar + KCl \rightarrow \Lambda$ events as a function of $p_\perp$ and $p_\parallel$ in the nucleus-nucleus c.m. at 1.8 GeV/u. a) Scatterplot of the data. The hatched curve shows the region where events were excluded as indicated in the text. The solid curve corresponds to the $NN \rightarrow \Lambda KN$ kinematic limit. b) Linear contour plot of the results for the Monte Carlo calculation AA (Fermi motion only). c) Linear contour plot of the calculation RsII with subsequent Λ rescattering (see text).

Table I

	$\langle p_\perp \rangle$ (GeV/c)	σ (GeV^2/c^2)	$\langle \lvert p_\parallel^{cm} \rvert \rangle$ (GeV/c)	σ (GeV^2/c^2)
Data	0.493	0.243	0.429	0.264
NN	0.122	0.077	0.117	0.077
AA	0.207	0.150	0.212	0.154
AA(Δ)	0.227	0.163	0.247	0.179
RsI	0.220	0.180	0.229	0.184
RsII	0.276	0.233	0.641	0.380



XBL 804-753

Fig. 1

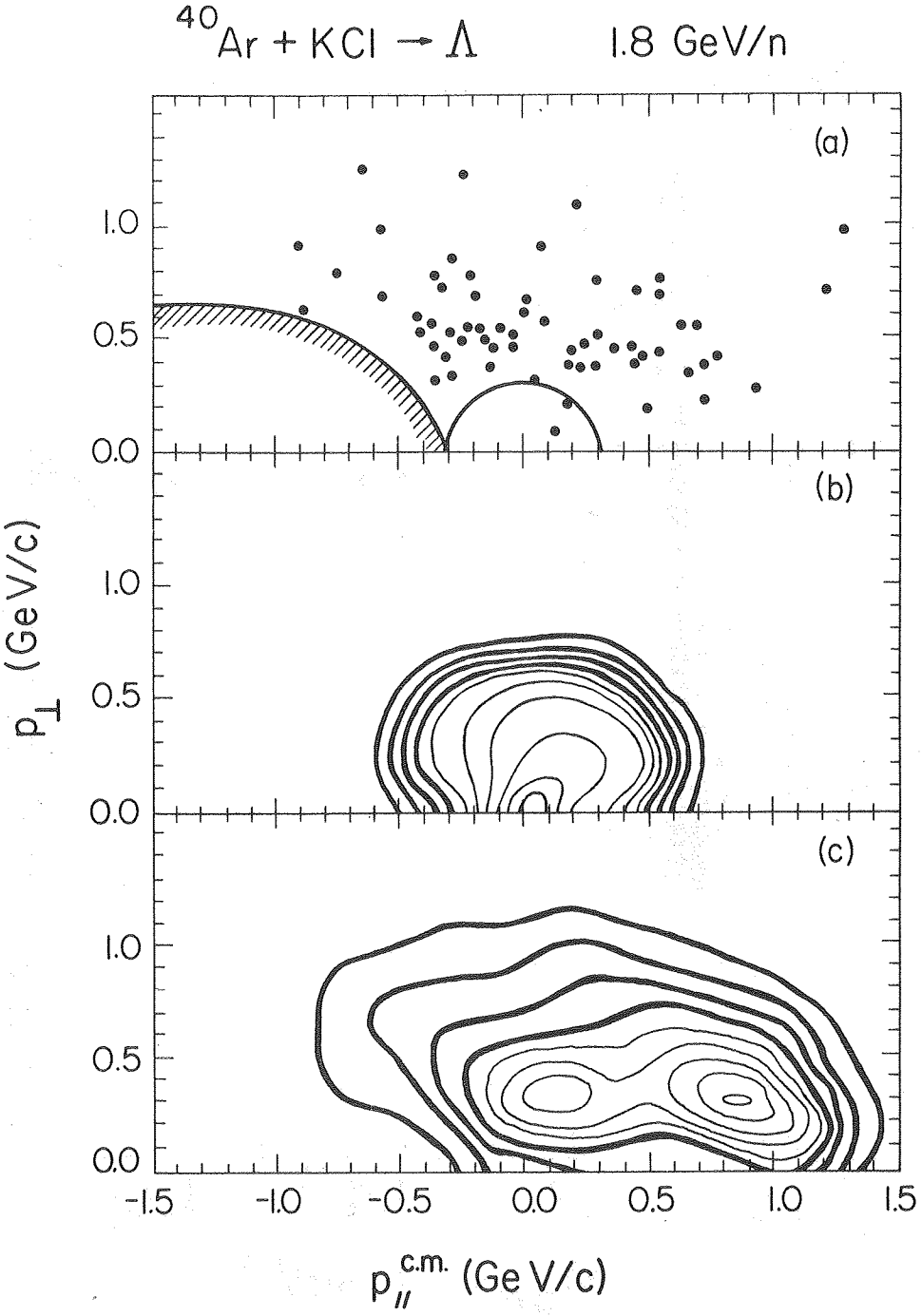


Figure 2

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